Annual Report

Project: NASA AISRP NNG04GP89G

Title: Block-Adaptive Parallel Implicit Methods for Semirelativistic Multifluid Hall-MHD

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Performance Period: October 1, 2004 through September 30, 2005

During the first year of this project we focused on several areas:

1. Analytic work in preparation for new Riemann solvers for the multispecies, semirelativistic MHD equations,
2. Investigations of various implementation techniques of general resistivity models in high-performance, adaptive MHD codes, and
3. Implementation and application of a multispecies MHD technique.

Significant progress has been accomplished in all three areas. Below we summarize our main accomplishments in more detail.

1. We analyzed the conservative formulation of the multispecies, semirelavistic, resistive and Hall MHD equations and derived the eigensystem of the equations in various approximations. In general, the system is very complicated and can only be evaluated numerically. Particularly challenging is the determination of regions where the system is hyperbolic (all eigenvalues are real). These eigenvalues play a fundamental role in constructing approximate Riemann solvers. In turn, the Riemann solvers are at the heart of upwind, high-resolution numerical schemes that are the foundation of modern, high-performance numerical codes. Significant progress has been made in this area and next year we will start implementing several approximate Riemann solvers.
2. We investigated several general implementations of resistivity effects in conservative, adaptive and massively parallel MHD codes. It turns out that there some subtle theoretical issues that needs to be addressed for accurate and robust resistive methods. After making a number of false starts and mistakes, we finally worked out a new formalism that ensures conservation of mass, momentum, energy and magnetic flux even for complicated, time-dependent resistivity models. The method has been implemented in the BATS-R-US parallel adaptive MHD code as well as in the Space Weather Modeling Framework (SWMF). The application of this new technique resulted in several science publications and presentations.
3. We developed a new, conservative method to solve the multispecies MHD equations and implemented the method in BATS-R-US and SWMF. The method has been applied to Saturn and Mars, two high priority target of NASA. The new method has been used to accomplish new scientific results that were published in peer-reviewed journals and presented at national and international conferences. It should be noted that one of the publications was in Science, the most prestigious peer reviewed journal.

Publications

1. G. Toth, D.L. De Zeeuw, T.I. Gombosi, and K.G. Powell, A parallel explicit/implicit time stepping scheme on block-adaptive grids, *J. Comput. Phys.*, submitted, 2005.
2. G. Toth, I. V. Sokolov, T. I. Gombosi, D, R. Chesney, C. R. Clauer, D. L. De Zeeuw, K. C. Hansen, K. J. Kane, W. B. Manchester, R. C. Oehmke, K. G. Powell, A. J. Ridley, I. I. Roussev, Q. F. Stout, O. Volberg, R. A. Wolf, S. Sazykin, A. Chan, and Bin Yu, Space Weather Modeling Framework: A new tool for the space science community*, J. Geophys. Res.*, doi:10.1029/2001JA007547, submitted, 2005.
3. M. Watanabe, K. Kabin, G. J. Sofko, R. Rankin, T. I. Gombosi, A. J. Ridley, and C. R. Clauer, Internal reconnection for northward interplanetary magnetic field, *J. Geophys. Res.*, 110, A06210, doi:10.1029/2004JA010832, 2005.
4. T.I. Gombosi and K.C. Hansen, Saturn's Variable Magnetosphere. *Science*, 307, 1224-1226, 2005.
5. Y. Ma, A. F. Nagy, I. V. Sokolov and K. C. Hansen,3D multi-species, high spatial resolution MHD studies of the solar wind interaction with Mars, *J. Geophys. Res., 109*, A07211, doi:10.1029/2003JA010367, 2004.
6. Y. Ma, A. F Nagy, T. E. Cravens, I. V Sokolov, J. Clark, and K. C. Hansen, 3D Global MHD model Prediction of the first close flyby of Titan by Cassini, *Geophys. Res. Lett., 31*, 10.1029/2004GL021215, 2004.

Invited Presentations

7. T.I. Gombosi, Severe weather in space, NASA ESTO Technology Conference, Adelphi, MD, June 28-30, 2005.
8. T.I. Gombosi, D.L. De Zeeuw, I.V. Sokolov, G. Tóth, A.J. Ridley, K.C. Hansen, W.B. Manchester, I.I. Roussev, C.R. Clauer, K.G. Powell, Q.F. Stout, B. van Leer, P.L. Roe, Parallel, Adaptive, Coupled Plasma Simulations, Multiscale Processes in Fusion Plasmas, IPAM UCLA, Los Angeles, CA, January, 2005.

Contributed Talks

9. M.M. Kuznetsova, Hesse, M., Rastaetter, L., Toth, G., De Zeeuw, D. L., Gombosi, T. I., Fast Magnetotail Reconnection: Challenge to Global MHD Modeling, 2005 Spring AGU Meeting, New Orleans, LA, May 23-27, 2005.
10. M.M. Kuznetsova, Hesse, M., Rastaetter, L., Gombosi, T. I., Intermittent Reconnection, Flux Ropes and Vortices Generation at the Dayside Magnetopause, 2004 Fall AGU Meeting, San Francisco, CA, December 13-17, 2004.